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effort was to involve scenario analyses, sensitivity analyses and external evaluations by experienced DOD officers and corporate managers. It was also intended to demonstrate the use of the simulation as a management tool for developing and evaluating alternative incentive schemes.

The major practical use of building a DPM type simulation is its ultimate application in answering "what if" type policy questions involving the design parameters of the contractual relationship between the DOD and defense contractors. For example, the simulation results indicated that increasing the contractor's fee improves cost control performance. This idea has recently been implemented by the Navy with measurable success. Another example involves the weight given to past performance in awarding new contracts. The DPM simulation results suggest that the higher the weight (including those assigned to the quality of the proposal) the better the cost control performance and social efficiency (i.e., amount billed to DOD as well as cost overruns, if any absorbed by contractor). Factoring past performance into the contract award decision was supported by the senior DOD officers interviewed. The practical implications involve the feasibility of factoring past performance measures into a DOD contracting environment where often it is difficult to maintain a second source and where such evaluation is considered to be extremely subjective.

The research effort demonstrates the value of such a simulation model for analyzing alternative acquisition policies (e.g., the importance of maintaining stable demand, weighting past performance, etc.) and the design of contract incentives (size of fee, schedule of progress payments, target and ceiling costs and sharing proportions). In particular it could augment traditional analytical and intuitive approaches to these issues. Its future application in acquisition policymaking will depend on implementing its use within the relevant command responsible for acquisition policies and the design of incentive contracts.

A simulation model of this type has other uses. Of particular interest should be its potential use in the training or education of policy makers and or DOD project managers. In business education similar simulation models have been designed as management games. Such games, which can be extremely complex, are used as laboratories for training students to apply analytical tools and integrate functional area knowledge (marketing, production, accounting, financial planning, etc.) within a competitive decision making environment. The DPM simulation has the potential to be integrated into an "Acquisition Game" and/or a "Project Management Game" for project managers. It could also be used in the education of policy makers (e.g., Congressmen, senior staffs) when they need to develop insights into DOD acquisition policies. The current state of the DPM simulation cannot be immediately used in acquisition training. However, it should be at the core of an acquisition game which could be designed.

In summary, the overall research effort has resulted in a simulation model involving the DOD and the contractor organization at the corporate and project management levels. The simulation has been shown to be internally robust and to satisfy certain face validity criteria as determined by the external validation interviews. In particular its potential application to acquisition related policy making (e.g., design of contract incentives) has been demonstrated. It is in the area of contributing to policy making and project management training where future developments need to be directed.

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DECISION PROCESS MODELS OF CONTRACTOR BEHAVIOR: THE DEVELOPMENT OF
EFFECTIVE CONTRACT INCENTIVES (PHASE II)

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EXECUTIVE SUMMARY

The overall research project involved the development of a computer simulation model (DPM) which describes the organizational and contractual interaction of the defense contracting firm with the DOD by focusing on the decision process at the project management level--i.e., decisions which ultimately determine the performance of the contractor on a given project. An objective of this research was to develop a capability to model the potential impact of various incentive schemes on the performance of defense contracts. It was necessary, therefore, to incorporate in the simulation model such basic elements as DOD project goals, DOD incentive mechanisms, contractor goals, and contractor organizational response mechanisms. Each of these elements, which collectively determine the behavioral pattern of the decision process model (DPM), are decoupled and parameterized to facilitate analysis of different incentive schemes and/or behavioral assumptions.

The objective of this contract was to validate the DPM simulation and its application to developing and testing alternative incentive schemes. Specifically this validation effort was to involve scenario analyses, sensitivity analyses and external evaluations by experienced DOD officers and corporate managers. It was also intended to demonstrate the use of the simulation as a management tool for developing and evaluating alternative incentive schemes.

The major practical use of building a DPM type simulation is its ultimate application in answering "what if" type policy questions involving the design parameters of the contractual relationship between the DOD and defense contractors. For example, the simulation results indicated that increasing the contractor's fee improves cost control performance. This idea has recently been implemented by the Navy with measurable success. Another example involves the weight given to past performance in awarding new contracts. The DPM simulation results suggest that the higher the weight (including those assigned to the quality of the proposal) the better the cost control performance and social efficiency (i.e., amount billed to DOD as well as cost overruns, if any absorbed by contractor). Factoring past performance into the contract award decision was supported by the senior DOD officers interviewed. The practical implications involve the feasibility of factoring past performance measures into a DOD contracting environment where often it is difficult to maintain a second source and where such evaluation is considered to be extremely subjective.

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A simulation model of this type has other uses. Of particular interest should be its potential use in the training or education of policy makers and or DOD project managers. In business education similar simulation models have been designed as management games. Such games, which can be extremely complex, are used as laboratories for training students to apply analytical tools and integrate functional area knowledge (marketing, production, accounting, financial planning, etc.) within a competitive decision making environment. The DPM simulation has the potential to be integrated into an "Acquisition Game" and/or a "Project Management Game" for project managers. It could also be used in the education of policy makers (e.g., Congressmen, senior staffs) when they need to develop insights into DOD acquisition policies. The current state of the DPM simulation cannot be immediately used in acquisition training. However, it should be at the core of an acquisition game which could be designed.

In summary, the overall research effort has resulted in a simulation model involving the DOD and the contractor organization at the corporate and project management levels. The simulation has been shown to be internally robust and to satisfy certain face validity criteria as determined by the

external validation interviews. In particular its potential application to acquisition related policy making (e.g., design of contract incentives) has been demonstrated. It is in the area of contributing to policy making and project management training where future developments need to be directed.

SECTION 1: INTRODUCTION AND BACKGROUND*

1.1 Overview

A major premise of incentive contracts as applied by the DOD in the development and procurement of new weapon systems is that defense contracting firms are primarily motivated to maximize profits. Research, however, suggests that the goal structure of contractors consists of survival, growth, market share, and reputation as well as profit. Furthermore, the relative operational importance of these goals is observed to be significantly influenced by the position and responsibility of the relevant decision maker within the contracting organization.

Survival is perceived by contractor management to depend on attaining project performance objectives which affect company reputation and the ability to obtain future business. Maintaining quality technical and administrative personnel, even in the face of declining business activity, is also thought to be critical to securing future large-scale contracts. Growth in market share is pursued as a means to improve internal capabilities, develop barriers to entry by potential competitors, and as a means to spreading fixed

* This section is adapted from the "Executive Summary" of the Final Technical Report on Contract # F33615-79-C-5151. A variation of this section has been published as Daniel L. Blakeley, Kalman J. Cohen, Arie Y. Lewin, and Richard C. Morey, "Assessing Defense Procurement Policies", Simulation, March 1982, pp. 75-83.

costs over a larger base. In short, contractor management (at various levels) is observed to voluntarily sacrifice short-run profits on a given DOD contract in favor of:

- a) improving opportunities for future follow-on projects,
- b) promoting technology spin-offs to commercial businesses,
- c) acquiring or maintaining quality personnel in scarce disciplines, and/or
- d) gaining competitive advantage by engaging in research instrumental to future product development.

The typical prime defense contractor is considered to have a DOD business base with an organizationally distinct commercial business (see Exhibit 1.1). The defense business, managed by a project manager (PM), consists of a number of projects awarded by the DOD. Likewise, the commercial business consists of a number of product lines, some of which benefit from technology developed under DOD contracts. In addition, indirect costs of the commercial sector may potentially be transferred to DOD projects due to the establishment of a larger overhead base.

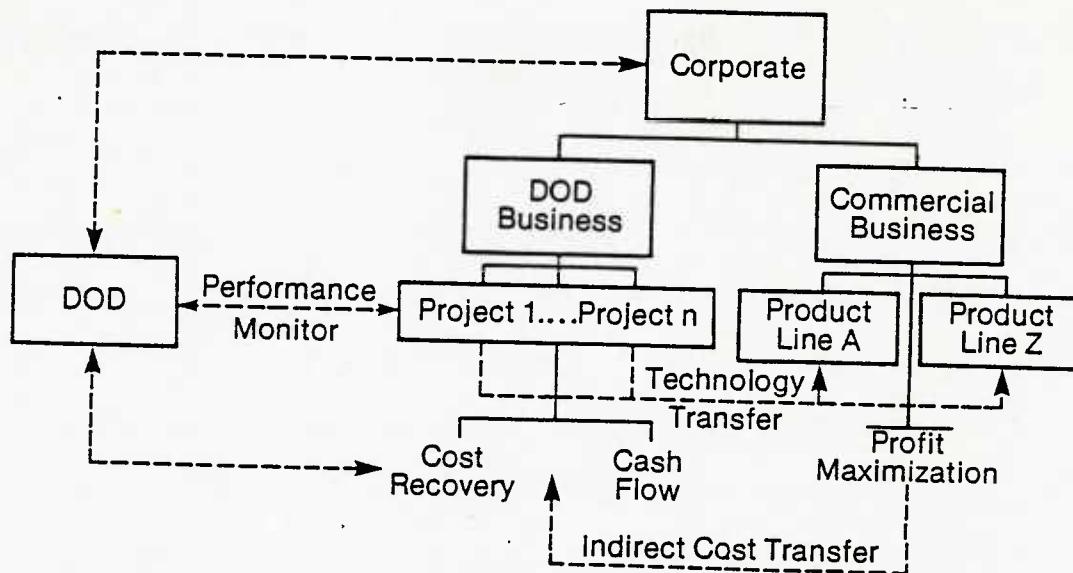


Exhibit 1.1

While the commercial sector of the firm may be based on profit maximizing considerations, the DOD business strategy focuses on achieving survival, growth, and prestige goals subject to maintaining a necessary level of cash flow. While a manager in the commercial market environment affects revenues by control of such variables as price, product attributes, production levels, inventory, etc., the manager of DOD projects has little operational control over standard economic decision variables as they are determined externally via contractual negotiations. Revenue is based on cost recovery; specifically on the recovery of direct and indirect costs billed against existing projects. A fundamental failure of past research has been the lack of a clear-cut understanding of the differences between doing business in

the traditional market environment and the defense contracting environment described above.

This research project involved the development of a computer simulation model which describes the organizational and contractual interaction of the defense contracting firm with the DOD by focusing on the decision process at the PM level--i.e., decisions which ultimately determine the performance of the contractor on a given project. An objective of this research was to develop a capability to model the potential impact of various incentive schemes on the performance of defense contracts. It was necessary, therefore, to incorporate in the simulation model such basic elements as DOD project goals, DOD incentive mechanisms, contractor goals, and contractor organizational response mechanisms. Each of these elements, which collectively determine the behavioral pattern of the decision process model (DPM), are decoupled and parameterized to facilitate analysis of different incentive schemes and/or behavioral assumptions.

1.2. Simulation Environment

The DPM consists of eight loosely coupled sub-models which operate on three organizational levels: the project manager level, the corporate level, and the DOD level. Each organizational level contains a separate set of goals, expectations, and decision processes which are simulated by the appropriate sub-models (discussed below). Various operational factors and project requirements are also important dimensions of the simulation environment. The synthesis

of these goals and constraints into an operational plan by the project manager is the foundation of the DPM (see Exhibit 1.2).

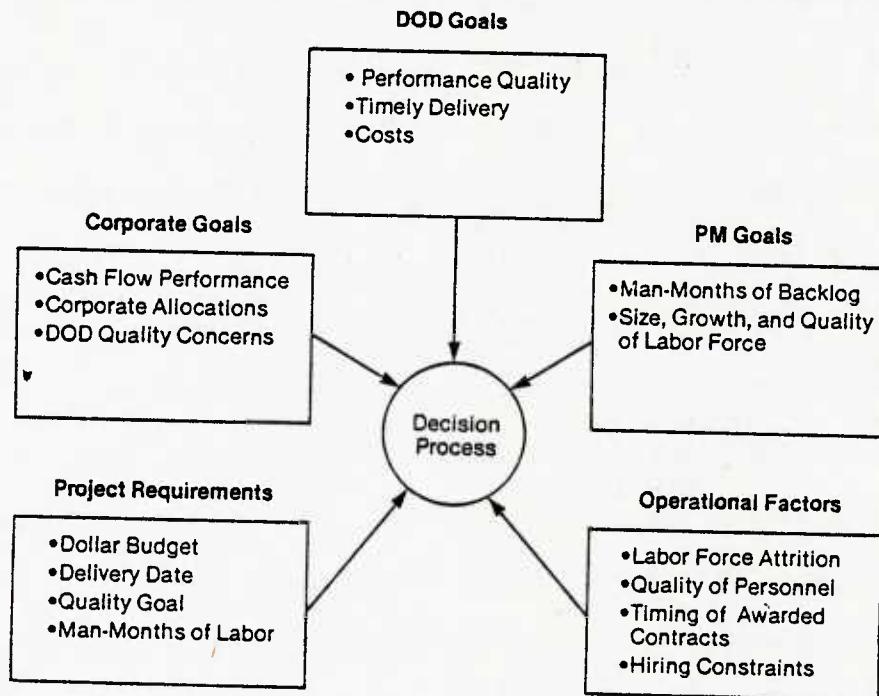


Exhibit 1.2

The DPM was designed to simulate the actions of a project manager in a defense contracting firm and the inter-dependent actions of corporate and DOD management in a dynamic framework. As means to simplifying the design of the simulation (but consistent with accepted simulation methods) decisions of the project manager are made on a monthly basis, while corporate decisions are made quarterly based on the project manager's previous three-month performance. The DOD is also interested in the project manager's actions, but only as they influence project performance. The DOD is able to monitor specific project performance attributes on a monthly (but delayed) basis.

Contracts awarded by the DOD consist of heterogeneous projects with several distinguishing attributes. Each project is considered either a Major Project (e.g., a weapon system awarded on a competitive basis) or a (significantly smaller) Spinoff Project (e.g., extension, enhancement, maintenance) with a dollar budget, delivery date, and an amount of standard quality of man-months (SQMMs) of work to be performed. In addition, Major Projects require that a specific quality standard be attained before the project is considered acceptable for delivery to the DOD.

A primary goal of the project manager (PM) is to control the backlog of awarded projects within maximum and minimum boundaries. The mechanism by which man-months of backlog may be influenced (besides the obvious effects of hiring and firing) involves the assignment of workers under the PM's responsibility to indirect activities. By increasing the size of the indirect work force, the PM is able to increase the number of proposals submitted to the DOD. Likewise, by improving the quality of personnel writing proposals, the PM is able to increase the capture rate of the resultant proposals. The quantity and quality of submitted proposals, in addition to performance on previous contracts, is assumed to determine the subsequent awarding of new projects by the DOD. Thus, by increasing the size or quality of the indirect (proposal writing) work force, the PM is able to increase the number of awarded projects and, all else equal, the man-months of backlog.

A secondary, but related, concern of the PM involves the quality, size, and growth of the technical staff. The work force consists of high and low quality personnel which are assumed distinguishable to the PM in the implementation of worker assignment and hiring/firing decisions. As in the real world, limits exist on the availability of high quality workers. However, it is assumed that the PM is able to hire low quality (inexperienced) personnel as necessary to fulfill labor requirements. Relative to inexperienced personnel, high quality workers are assumed to have higher voluntary turnover rates, higher salaries and higher marginal productivity. In general, the DPM simulates the project manager (PM) pursuing, subject to various operational constraints and pressures (discussed below), the attainment of personal backlog and staffing goals by implementing specific work force assignment and hiring/firing decisions on a monthly basis.

The corporate-level, on the other hand, is concerned with the cash flows, cost overruns and the resultant impact on the financial position of the firm. If the quarterly performance is unsatisfactory, pressure is applied on the project manager to increase cash flow. The PM is able to improve cash flow by increasing the amount of billable time charged against existing contracts (i.e., increase the number of workers on direct activities) and/or decrease current cash expenses (i.e., implement firing decisions). An additional concern of corporate is the level of allocations in support

of IR&D and administrative expenses levied on the PM's organization.

Finally, the DOD monitors the performance of the PM with respect to individual projects. Specifically, the DOD is concerned with: a) total costs as determined by cumulative billings against a contract; b) performance quality as reflected in the average quality of personnel used in satisfying the SQMM requirement; and c) the time period in which the product is available relative to the contracted delivery date. The exhaustion of the SQMM balance does not necessarily coincide with that of the dollar budget and, dependent on the contract type utilized, excess costs are not fully billable to the DOD. When quality or schedule problems are identified by the DOD, pressure is applied on the PM. If project manager pressure does not result in improved performance, the DOD may convey its concerns to the corporate-level, dependent on the severity of the problem.

In summary, the interaction of the various organizational levels and their associated goals and expectations combined with the many operational factors and constraints faced by the PM provide a realistic operating environment for the DPM. The DPM also demonstrates interesting dynamic properties in that PM and corporate-level goals are modified throughout the simulation, dependent on prolonged success or failure. (DOD goals are assumed static and determined with the awarding of a contract.) Exhibit 1.3 illustrates the

dynamic interaction of the PM, corporate, and DOD organizational levels during the course of a simulation.

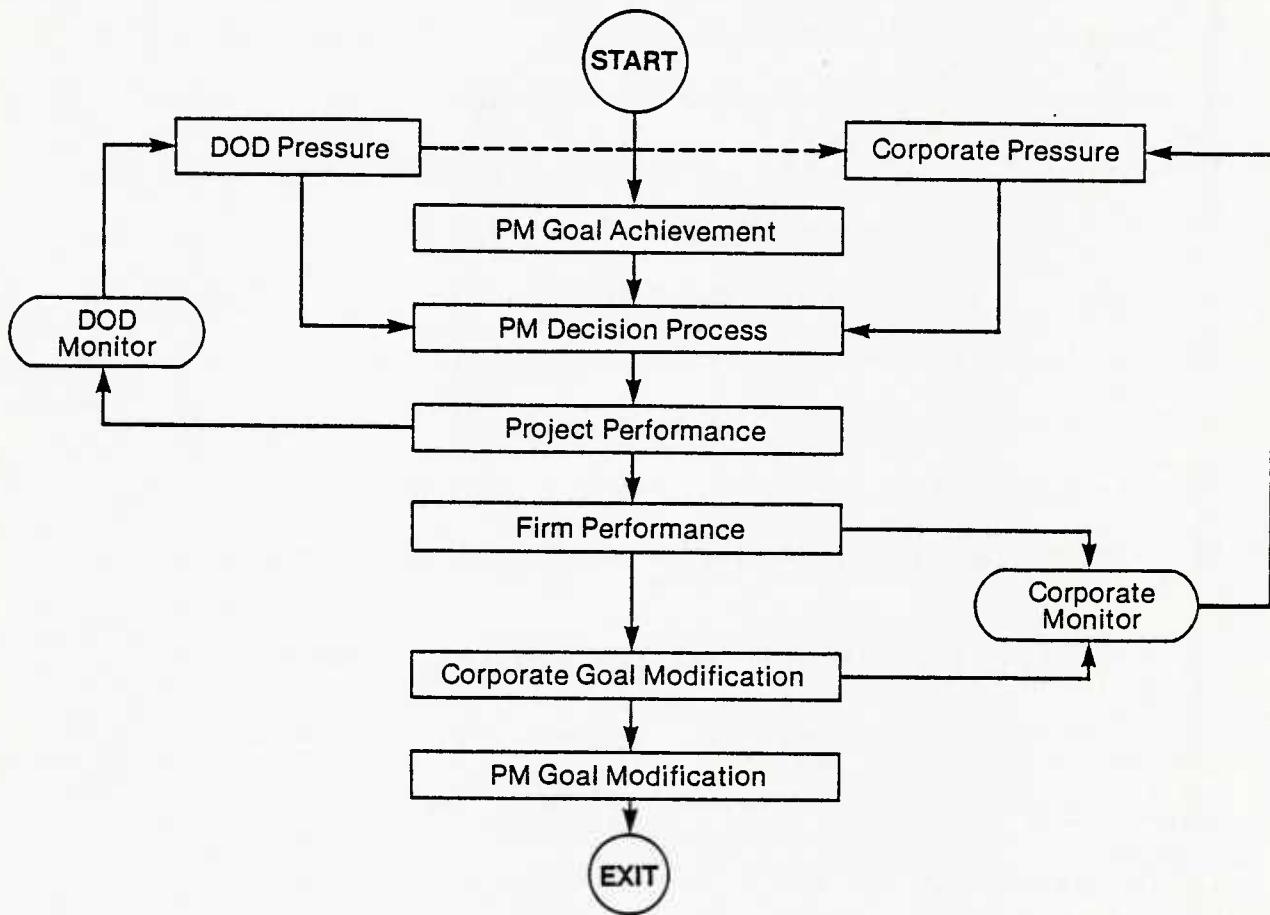


Exhibit 1.3

1.3. Model Decomposition

Exhibit 1.4 provides a listing and ranking of the various pressures and goals facing the PM as they were incorporated into the DPM logic flow. The paramount concerns of the PM involves Corporate Cash Flow Pressure, DOD Schedule Pressure, and/or Deficient Quality on a completed project. The PM is assumed to address these occurrences before considering remaining problems. Other pressures and unsatisfied

goals are not ignored, but are given secondary consideration if they are in conflict with higher ranking priorities.

The next level of influence on PM behavior is Corporate Quality Pressure which is triggered when DOD quality pressure is communicated to the corporate-level, and then relayed to the PM. The DOD, as mentioned, approaches the corporate-level with quality concerns only if previous DOD Quality Pressure has been ineffective. As illustrated in Exhibit 1.4, this may occasionally occur as the Backlog Goal of the project manager takes precedence over DOD Quality Pressure. Finally, the Volume Goal of the project manager is the lowest ranking consideration in the attention hierarchy.

Determinants of Project Manager Behavior

- Level 1: Corporate Cash Flow Pressure
DOD Schedule Pressure
Deficient Quality on Completed Project
- Level 2: Corporate Quality Pressure
- Level 3: Backlog Goal
- Level 4: DOD Quality Pressure
- Level 5: Volume (staff) Goal

Exhibit 1.4

1.3.1. PM Manpower Assignment Sub-Model

The purpose of the PM Manpower Assignment Sub-Model is to assign each high and low quality worker to indirect proposal development activities or to a specific project. As discussed, the PM is assumed to make

personnel allocation decisions based on the existence of various DOD and corporate pressures, the achievement of personal goals and individual constraints due to backlog of incomplete projects.

1.3.2. Project Update Sub-Model

Based on the personnel allocation decision made by the PM with respect to the quantity and quality of work performed on each project, several running measures are updated for each project worked on. Specifically, the remaining dollars in the budget and the required SQMM balance must be decreased and the quality index of work performed adjusted accordingly. Finally, the time remaining before each project is due is calculated.

1.3.3. Personnel Sub-Model

The objective of the Personnel Sub-Model is to implement the decisions made by the PM with respect to alterations in the size of the work force. Labor force attrition is also reckoned with in this sub-model and is assumed to occur simultaneously with the PM's hiring/firing decision--i.e., the PM is unable to compensate for attrition in the current period. The output of the Personnel Sub-Model is a description of the end-of-the-period labor force in terms of size and quality composition.

1.3.4. Backlog Determination Sub-Model

Based on the output of the previous sub-models, the Backlog Determination Sub-Model calculates the number of

months of backlog (given current staffing levels) at the end of the period. This involves determining whether a project has been awarded and, if so, the dollar, delivery date and SQMM size of the new project.

1.3.5 Cash Flow Determination Sub-Model

The Cash Flow Determination Sub-Model calculates the direct and indirect costs associated with the PM's operation and the cumulative billings to the DOD allowed for the direct work performed on individual projects. Billings against a particular project are allowed only if the budget has not been depleted. Once the target cost on a given project has been reached, the contractually specified cost-sharing formula allocates subsequent cost-overruns between the contractor and the DOD. If the ceiling cost is exceeded, all further expenses incurred on a given project in satisfaction of SQMM requirements and/or quality standards are fully absorbed by the contractor.

1.3.6 Corporate Goal Adjustment Sub-Model

The output of the Corporate Goal Adjustment Sub-Model is a determination of the level of appropriations in support of corporate administrative and IR&D expenses that is levied on the PM's operation. Also a decision as to whether to apply cash flow pressure on the PM is calculated in this sub-model.

1.3.7 PM Goal Adjustment Sub-Model

The PM Goal Adjustment Sub-Model is responsible for modifying the PM's personal Backlog and Volume goals based on the success of past and current performances and the existence of pressures from corporate and DOD levels.

1.3.8 DOD Sub-Model

The DOD Sub-Model monitors progress made on each of the projects awarded to the defense contractor and determines whether schedule and/or quality pressure should be applied at the PM or corporate levels.

1.4 Model Solution

All sub-Models have several functional categories which collectively describe the work flow during the solution sequence. Each sub-model, except several routines in the Corporate Goal Adjustment Sub-Model (which are solved quarterly), are solved each time period of the simulation.

As shown in Exhibit 1.5, the simulation begins with solution of the PM Manpower Assignment Sub-Model. This involves the PM review of the operating environment (see Exhibit 1.3) taking note of various pressures and goal achievement. The labor force is then broken down between indirect and direct activities and assigned to specific tasks; either proposal writing or to an incomplete project. Decisions are also made concerning hiring or firing. After solution of the PM Manpower Assignment Sub-Model, each

project in the backlog is updated through solution of the Project Update Sub-Model.

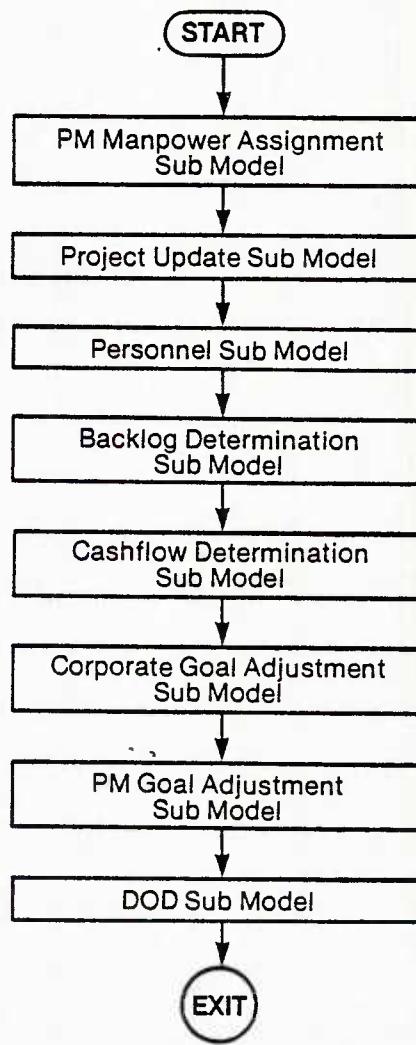


Exhibit 1.5

The Personnel Sub-Model is then solved which determines the size and quality composition of the labor force at the end of the period--taking into account the hiring and firing decisions of the project manager and labor force attrition. The Backlog Determination Sub-Model utilizes the output of

the Personnel Sub-Model and calculates the actual months of backlog in the PM's incomplete project inventory at the end of the period. This also requires determining if a new project has been awarded in the current period.

After solution of the Cash Flow Determination Sub-Model, the Corporate and Project Manager Goal Adjustment Sub-Models are solved. Finally, the DOD Sub-Model which monitors individual project performance, is solved.

1.5. Objectives of Contract F33615-81-C-5034

The effort under contract F33615-79-5151 was devoted to the development of the Multi Project DOD Dependent Firm Computerized Decision Process Simulation described above. The objective of contract F33615-81-C-5034 was to validate the DPM simulation and its application to the development and testing of alternative incentive schemes. Specifically the validation phase was to involve scenario analyses (Section 2), sensitivity analyses (Section 3) and external evaluations by experienced managers (Section 4). It was also intended to demonstrate the use of the simulation as a management tool for developing and evaluating alternative incentive schemes.

SECTION 2: SCENARIO GENERATION AND ANALYSES

2.1 Overview

The specific objectives of the scenario Generation and Analysis phase were: a) to analyze in detail the simulated output of two scenarios as plausibility checks of DPM consistency and reasonableness, and b) to demonstrate how the DPM may be utilized to investigate alternative procurement policies of the DOD and business strategies of defense contractors. In the scenario analyses the DPM is solved over 72 decision making intervals which are equivalent to six years of monthly and quarterly decision adjustments. One year or 12 periods of historical data is necessary to initialize the simulation. The database was designed to allow the project manager (PM) to simultaneously manage a maximum of 10 separate projects in any given time period. No constraint was placed on the number of projects which may be awarded over the 72 month horizon of the simulation.

2.1.1 Scenario 1: Standard Simulation

Scenario 1 is considered the standard to which other simulations are compared. The assumption was made that the project manager is awarded a Major Project in period 1 and no other Major Projects are obtained throughout the simulation. No mechanism is currently specified which translates corporate IR&D allocations into Major Projects. Because the project manager is not awarded another Major Project, his backlog and volume

goals (as well as associated corporate and DOD concerns) must be satisfied by the attainment of new spinoff projects and the completion of the initial Major Project.

2.1.2 Scenario 2: No DOD Monitor

The purpose of generating this scenario was to investigate the effect of the DOD monitor (and the associated quality and schedule pressure mechanism) on the behavior of the project manager and on overall system performance. For this scenario it is assumed that the DOD will not apply schedule or quality pressure at the corporate or project manager level. It is further assumed that the DOD will not accept the major project unless the minimum contractually specified quality goal has been achieved. Additional high quality work is required if the quality of an otherwise completed project is less than the minimum acceptable standard. As in Scenario 1, only one Major Project is assigned to the project manager.

2.1.3 Summary

For each of the scenarios, the time trends of important variables were analyzed from the perspective of the project manager, corporate management and the DOD. The results which are reported in technical report #1 support the reasonableness of the DPM in month 13-72 (the first 12 months of each simulation run are needed for initializing the DPM).

2.2 DOD Policy Experimentation

This phase was intended to demonstrate how the DPM may be utilized as a management tool in the formulation and evaluation of alternative procurement policies by the DOD. The example which was developed as part of the contract was for illustrative purposes and should not be interpreted as an evaluation of existing policies or recommendations for improvement.*

The policy experiment was based on a set of DPM scenarios that were generated as a means of investigating the effectiveness (with respect to project performance) of two policy instruments. Both instruments, or control variables, are contractual specifications dealing with the allocation of project costs. The first involves the "share" formula which determines the percent of actual costs greater than target-but less than ceiling--that must be absorbed by the contractor (i.e., non-reimbursable cost overruns). Most attention in the literature has been given to the optimal specification of the sharing proportion or "share". The second policy instrument analyzed concerns the setting of ceiling relative to target costs or the "range" of ceiling cost over target cost.

* This section and 2.3 were derived from Sections 1.4 and 1.5 of Technical Report #1, pp. 28-38.

A serious problem associated with standard models of incentive contracting is a computational limitation of concurrently evaluate multiple DOD goals (e.g., cost, schedule, quality) and policy instruments (e.g., target and ceiling costs, sharing proportion, progress payments and project award algorithm). The DPM methodology is particularly well-suited to deal with this common deficiency.

2.2.1 Multiple-Scenario Generation

In order to evaluate the effectiveness of a given policy, or combination of policies, it is necessary to:

- a) determine that the simulation model is a reasonably accurate representation of firm behavior based on observations of past performance, DOD policies and contractor operating strategies, b) identify and define performance output variables of interest to policy makers, and c) assign a feasible range of experimental values to the policy instrument(s) under consideration.

The overall concern of this research project is focused on the first criteria. This section addresses criteria b and c.

The following performance indicators are evaluated over a 5 year simulation horizon:

Production Volume	-	the total volume of work performed as reflected in the cumulative SQMM's (Standard Quality Work, Month of Work) of all completed projects,
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Performance Quality	-	the average quality of completed projects weighted by their respective SQMM size,
Performance Efficiency	-	the average cost to the DOD per completed SQMM and the total cost (including the contractor's share) per SQMM,
Cost Control Efficiency	-	the average cost overrun per project as a percent of target costs, and,
Schedule Performance	-	the average number of months late per completed project.

As mentioned above, two policy instruments are being evaluated: the contractor's share of cost overruns and the range of ceiling over target cost. The basic Standard Scenario is solved over 72 periods (12 time periods are required for initialization) for each possible combination of values assigned to the two policy instruments. Three values--low, medium and high--have been chosen for each instrument: 15%, 40% and 75%, respectively, for the sharing proportion and 110%, 125% and 150%, respectively, for the range. The low values are typical of prevalent incentive contracts. The medium and high values have been chosen to represent more extreme options.

2.2.2 Policy Analysis

Table 2.1 displays the results of the policy experiments with respect to the volume of work (SQMM's) performed. (The effect of a given policy on performance

outcome, averaged over all values of the other policy instrument, is found at the end of the appropriate row or column.) There appears to be, for any given share, a strong tendency for higher ceilings to be associated with increased output. The average output of 3,299 SQMM's with a low ceiling (110% of target costs) compared with the significantly higher output of 3,920 SQMM's associated with a high ceiling (150% of target costs) suggests that all else equal, contractors interpret high ceilings as inducements to expand internal capacity (workforce). This tendency is also observed, to a lesser extent, in the effects of alternative sharing propositions: high shares (75%) result in an average output of 3,515 SQMM's while low shares (15% result in 3,602 SQMM's being completed). Thus, for policy makers primarily concerned with promoting high levels of production, a low sharing proportion combined with high ceiling costs appears to be appropriate.

Table 2.1 Production Volume (SQMM's)

Contractor's Share of Cost Overruns	Ceiling Cost as % of Target Cost			3,602
	110%	125%	150%	
15%	3,129	3,542	4,046	3,602
40%	3,278	3,674	3,903	3,618
75%	3,400	3,334	3,811	3,515
	3,299	3,517	3,920	

High ceilings and low shares, however, are associated with lower average quality performance. As shown in Table 2.2 the average effect of a high ceiling over all sharing proportions on performance quality is .840 while low ceilings result in an average quality of .848. Likewise, the average effect on performance quality of a low sharing proportion is .84 while a high share is associated with an average performance quality of .846.

Table 2.2 Performance Quality

		Ceiling Cost as % of Target Cost			
		110%	125%	150%	
Contractor's Share of Cost Overruns	15%	.847	.834	.840	.840
	40%	.848	.840	.839	.842
	75%	.848	.850	.840	.846
		.848	.841	.840	

These results suggest that a dichotomy exists between policies which promote high production volume and those which increase performance quality. In the first case, low sharing proportions combined with high ceilings incentivize the contractor to increase capacity because a large amount (50% of target costs) of low cost (15% share) funds become available to support workforce expansion. Rapid expansion of the workforce, however, decreases the quality of project performance due to the relative scarcity of high quality personnel. In addition, the project manager confronted with a larger

workforce utilizes a significant proportion of high quality personnel on proposal writing (rather than on direct production activities) due to the increased difficulties of maintaining an adequate backlog.

Table 2.3 provides a cost efficiency ranking of the various range/share policy combinations from the perspective of the DOD. As the results indicate, DOD cost per SQMM is not significantly influenced by alterations in the ceiling cost. As expected, high sharing proportions have a significant negative impact on DOD average costs per SQMM: \$6.01 and \$5.77 for low and high sharing proportions, respectively. More importantly, from the perspective of social efficiency, the total actual costs of development (including the contractor's share) as displayed in Table 2.4 is also decreased as the sharing proportion is increased. The average cost per SQMM over all ceiling values decreases from \$6.079 to \$.065 as the share is increased from 15% to 75%. In addition, average total costs increase (\$6.054 to \$6.090) as the ceiling cost is increased from 110% to 150%.

Table 2.3 DOD Cost Per SQMM (\$000)

		Ceiling Cost as % of Target Cost			
		110%	125%	150%	
Contractor's Share of Cost Overruns	15%	5.992	6.020	6.022	6.01
	40%	5.887	5.898	5.912	5.90
	75%	5.779	5.765	5.764	5.77
		5.89	5.89	5.90	

Table 2.4 Total Costs Per SQMM (\$000)

		Ceiling Cost as % of Target Cost			
		110%	125%	150%	
Contractor's Share of Cost Overruns	15%	6.055	6.092	6.091	6.079
	40%	6.052	6.079	6.090	6.074
	75%	6.054	6.061	6.080	6.065
		6.054	6.077	6.090	

The results presented in Tables 2.3 and 2.4 suggest that the sharing proportion may be a potentially useful policy instrument to control actual development costs--but only when sharing proportions approach levels of 40-75%. When sharing proportions are applied at low levels (see Table 2.4, 15-40%), very little cost improvement results. This is a direct result of the previously mentioned capacity and quality implications of low sharing proportions. High sharing proportions in the 40-75% range are shown to result in improved cost efficiency. The project manager faced with high sharing proportions (and to a lesser extent, low ceiling costs) is forced to run a "tight ship"--i.e., no unnecessary expansion in staff and/or overhead expenses.

Table 2.5 Cost Overruns as % of Target Costs

		Ceiling Cost as % of Target Cost			
		110%	125%	150%	
Contractor's Share of Cost Overruns	15%	7.41	8.43	8.12	7.99
	40%	7.27	8.06	7.93	7.75
	75%	6.45	7.16	7.45	7.02
		7.04	7.88	7.83	

The results of Table 2.5, display cost overruns as a percent of target cost for each of the range/share scenarios and are consistent with the results of Tables 2.3 and 2.4. Lower cost overruns are consistently associated with higher sharing proportions for any given ceiling. Again, it is important to note that a much greater effect is found with high sharing proportions rather than low.

Finally, Table 2.6 shows the average number of months late per completed project. While the sharing proportion does not show a directional effect on schedule delays, low ceilings (110-125%) seem to be significantly associated with schedule delays. The average overall sharing associated with a low ceiling is 3.26 months. With a high ceiling the average number of months late drops to .8. This association is consistent with the results shown in Table 2.1 for production volumes. Increased internal capacities due to low shares and high ceilings increase the likelihood that projects will be completed on time.

Table 2.6 Average Number of Months Late Per Project

		Ceiling Cost as % of Target Cost			2.60
		110%	125%	150%	
Contractor's Share of Cost Overruns	15%	3.23	4.57	0	2.12
	40%	2.92	3.43	0	2.71
	75%	3.64	2.08	2.4	
		3.26	3.36	.8	

2.3 Biased Cost Estimates and Project Performance

Much controversy has traditionally been associated with cost overruns and their viability as accurate indicators of contractor efficiency. It is generally accepted that biased cost estimates are an important factor in explaining cost overruns (i.e., "low-balling", "buying-in", etc.). The objective of this section is to demonstrate how the DPM may be utilized to investigate the multi-dimensional effect on project performance of biased cost estimating behavior.

The current experiment requires solving the DPM under the identical operating conditions (e.g., sharing proportion,

ceiling cost, etc.) of the Standard Scenario except that the initial estimated target cost is 25% below the previous estimated amount. (It will be recalled that the Standard Scenario involves a sharing proportion of 15% and a ceiling equal to 125% of target cost.) Table 2.7 presents the results of the 2 scenarios under consideration.

Table 2.7 Accurate vs. Biased Cost Estimates

	<u>Output Variable</u>	<u>Standard</u>	<u>Biased Estimate</u>
1.	Production Volume	3.542	3.599
2.	Performance Quality	.834	.846
3.	DOD Cost/SQMM	6.02	5.85
4.	Total Cost/SQMM	6.09	6.07
5.	Cost Control Efficiency	8.43	13.1
6.	Schedule Performance	4.57	1.07

A cursory examination of the data suggests that biased estimates do, in fact, influence project performance because all but 2 of the output variables (production volume and total cost per SQMM) are significantly different. A somewhat surprising result, at first glance, is that the performance quality, DOD cost per SQMM and schedule performance indices are improved when low initial cost estimates on the Major Project are submitted by the contractor. Relative to the Standard Scenario: quality has improved from .834 to .846, DOD cost per SQMM has been reduced from \$6.02 to \$5.85 and the average month's late per completed project has decreased from 4.57 to 1.07. As expected, cost control efficiency is significantly worse when low estimates are submitted.

As originally hypothesized, the project manager in the DPM is assumed to pursue operational goals concerning backlog and internal capacity (staff) in a fairly autonomous fashion as long as corporate and DOD goals are satisfied. When problems arise (i.e., unsatisfied goals), conflict between decision centers occurs and project manager goals may be compromised--dependent on the source and severity of the resultant pressure applied to the project manager.

A low target cost on the initial Major Project will, all else equal, result in the Project Manager's organization having a less favorable cash flow performance--especially as the SQMM requirement of the Major Project is nearing completion (time periods 40-45, approximately). This situation, and the resultant Cash Flow Pressure from the corporate level, will effectively prevent a significant expansion in staff normally associated with large contract awards. In addition, with a smaller monthly payroll fewer newly awarded projects (and high quality personnel on proposal writing activities) are required in order for the Project Manager to maintain backlog within acceptable boundaries. In short, low initial cost estimates on the Major Project prevent rapid expansion in internal capacity and the associated problems of a lower quality workforce and larger payroll (direct and overhead) obligations. Although short-run, operational problems may plague the contractor (e.g., vulnerable cash position, schedule slippages, employee morale and attrition) the long-run (5-year) effect on overall project performance

with respect to quality, production efficiency and delivery is improved.

2.4 Summary

Scenario analyses was utilized to explore the general behavioral pattern of the DPM and demonstrate how the DPM may be used to evaluate alternative procurement policies and investigate other problem areas of concern.

The next phase of the research involved a sensitivity analysis of the model by using regression techniques to examine the underlying determinants of model behavior. The DPM's many policy instruments, initial values and behavioral adjustment parameters are tested for their effect on important performance outcomes to determine whether the model application to real-world phenomena can be considered viable.

SECTION 3: SENSITIVITY ANALYSIS*

3.1 Overview

The objective of this phase was to investigate the underlying properties of the DPM in more detail. The procedures chosen to investigate the relationship between the DPM's exogenous factors (i.e., policy instruments, initial conditions and adjustment parameters) and endogenous responses (i.e., performance/behavior indices) was multiple regression analysis. It is, of course, impractical to attempt to investigate all factors of possible consequence due to the complexity of the DPM. The non-policy factors (i.e., initial conditions and behavioral adjustment parameters) that were investigated for significance were chosen based on a priori judgments of possible operational importance. However, all policy instruments currently specified (and identified) in the DPM were included in the sensitivity analysis.

Because of the many real-world intricacies of the system under study, the simulation model is likely to contain complexities which disguise important variable interactions which may appear intuitive and obvious, after analyzing simulated performance data, but are nevertheless difficult to comprehend beforehand. It is necessary, therefore, to use a good deal of a posteriori reasoning in order to adequately investigate the behavioral properties of the DPM.

* This section is based on Technical Report #2.

This is not meant to imply that none of the variable interactions evaluated as part of the sensitivity analysis have predictable relationships. To the contrary, many variables which were tested have predictable directional effects on specific performance indices. These straightforward associations are a direct result of the DPM's structure and internal specification. Furthermore, a good many of these intuitive relationships have been identified and analyzed in the course of describing various scenarios. For example, a workforce consisting of higher quality personnel is expected to contribute, all else equal, to higher performance quality. For the most part, however, the analysis focused on underlying properties which, while perhaps less intuitive, are equally important in understanding the operational behavior of the DPM. More specifically, behavioral properties of the DPM were investigated which may very well exist in the real world but are extremely difficult to comprehend in a non-controlled environment.

3.2 Basic Procedure of Analysis

The methodology used to investigate the sensitivity of DPM behavior to various internal factors is straightforward. The first step was to define key output/performance measures from the perspective of the DOD, Project Manager and Corporate Top Management. In addition, the appropriate time periods in which to observe their values must be identified.

The following performance variables were considered:

- $X1DOD_t$ - DOD schedule performance measure defined as the cumulative number of months late on all projects completed during the relevant time period divided by the number of completed projects,
- $X2DOD_t$ - DOD cost control performance measure defined as the cumulative cost overruns on all projects completed during the relevant time period divided by the cumulative target costs,
- $X3DOD_t$ - DOD quality performance measure defined as the average quality of all projects completed during the relevant time period weighted by their respective SQMM sizes,
- $X4DOD_t$ - DOD cost efficiency performance measure defined as the cumulative dollars billed on all completed projects during the relevant time period divided by their cumulative SQMM sizes,
- $X5DOD_t$ - social cost efficiency performance measure defined as the cumulative actual costs incurred on all completed projects during the relevant time period divided by their cumulative SQMM sizes,
- $Y1PM_t$ - Project Manager labor force volume measure defined as the average monthly size of the labor force over the relevant time period,
- $Y2PM_t$ - Project Manager backlog (security) measure defined as the average monthly size of the backlog over the relevant time period,
- $Y3PM_t$ - Project Manager labor force quality measure defined as the average quality of the labor force over the relevant time period,
- $Z1CORP_t$ - Corporate level cash flow performance measure defined as the cumulative net cash flows over the relevant time period, and
- $Z2CORP_t$ - Corporate level profitability measure defined as the cumulative net cash flows over the relevant time period divided by the cumulative billings to the DOD.

The DPM was solved over a time horizon of 72 periods or 5 years of monthly decision adjustments. (The reader will recall that 12 periods of historical data are required for initialization.) Each of the 100 quasi-observations which comprise the experimental database required a full solution of the DPM. Four time periods are considered for analysis: years 1-5, 2-5, 2-3, and 4-5. Years 1-5 are evaluated in order to capture the aggregate effect of variations in internal factors on the output variables defined above. However, in order to somewhat dampen the start-up effect of initial conditions on performance indicators, years 2-5 were chosen for more detailed examination. Finally, the 2-5 year time span is divided in order to investigate DPM behavior during and after completion of the Major Project -- which typically is completed in year 3.

3.2.1 Initial Conditions

Of the eight initial conditions analyzed, two were identified as having a fairly consistent influence on performance outcomes: the size of the Project Manager's workforce in the initial period of the simulation (LABOR) and the proportion of the initial workforce considered high quality (PH). As expected, larger capacity (staff) and higher quality personnel result in improved cost control performance. Social cost efficiency (total cost per SQMM) is also shown to improve with increases in the total workforce and the initial proportion considered high quality, although neither

variable significantly influences the cost to the DOD per SQMM. Finally, a higher quality initial workforce has the predictable effect on performance quality.

With respect to performance variables of interest to the Project Manager, high initial workforce quality facilitates the achievement of labor force goals and quality objectives as well as higher average backlogs. In each case, the directional effect of significant initial conditions on Project Manager performance variables are consistent with our intuition.

An interesting result is that cumulative cash flow performance is favorably influenced by increases in the size of the initial workforce. This is probably the result of the Project Manager having more billable time available to be charged against initial contracts and not having to hire additional workers. Initial backlog goals also positively influence cash flow performance. A Project Manager with greater concerns for maintaining high levels of backlog will be in a better position to afford extended periods of negative cash flow (or at least decrease their severity).

It should be mentioned that the significance of several initial conditions discussed above to various DPM performance indices is not unexpected or undesirable. In the first place, extremely large ranges of possible values were tested: the surprising result would have been if they were found to be inconsequential

to DPM performance. Secondly, the observed effects of variations in initial conditions can play an important role in validating the DPM by providing a plausibility check on reasonableness and consistency. For example, if significant increases in the initial endowment of high quality personnel had no effect whatsoever on performance outcomes, a re-evaluation of the DPM's internal specifications would be required.

3.2.2 Behavioral Adjustment Parameters

None of the behavioral parameters were significant at the 5% level except in one case. The log linear regression suggests that the average size of the Project Manager's backlog is negatively related to the rate at which workers are transferred from indirect to direct activities. The explanation for this relationship is self-evident once consideration is given to the mechanism by which the Project Manager controls the level of backlog.

Projects awarded by the DOD are assumed to be instigated by the submission of proposals prepared by personnel classified as indirect. The rate at which new proposals are generated is a function of the size of the indirect workforce. The higher the specific rate at which workers are transferred (when required) to direct activities, the fewer proposals are submitted and, the fewer projects awarded by the DOD.

3.2.3 DOD Policy Instruments

On the 13 DOD policy instruments investigated, 2 are clearly influential on DPM performance in that variations in their values are significantly associated (at the 5% level) with at least 50% of the performance variables. The weight assigned by the DOD to past contractor performance when assessing the attractiveness of a newly submitted proposals (henceforth referred to as the capture rate algorithm) is significantly associated with all output variables except DOD quality and cost efficiency performance. The higher the weights assigned to past project performance (i.e., mean and variance of past quality indices) the lower are cost in the long run and social efficiency. Higher weights on past performance (and in this case also to the weight assigned to proposal quality) are also associated with improved Project Manager staffing and backlog performances, but are negatively associated with the average quality of the workforce. This latter effect is a direct result of the large expansion in staff and the relative scarcity of high quality personnel. Finally, the weight assigned to past performance is shown to be positively associated with total cash flow performance and total cash flow as a percent of total billings.

The other policy instrument identified as having a significant influence on overall DPM performance is the scale parameter which adjusts (contractually specified)

target costs to an amount greater than or less than estimated costs. Higher target costs are shown to improve schedule performance, cost control, and project performance quality. Conversely, low target costs are associated with schedule delays, cost overruns and quality problems.

It is clear that higher target costs will, ceteris paribus, result in smaller cost overruns. Similarly, increasing target cost is synonymous with increasing cash flow potential and man-months of backlog associated with any given contract. By implicitly reducing the demands made on the Project Manager to win new contract awards, heretofore unutilized resources become available for direct project work--i.e., the size and quality of personnel assigned to writing new proposals is reduced. This, in turn, has the expected effect on project schedule and quality performance measures. It is interesting to note that increasing target cost also increases the size of the workforce and average level of backlog, but does not significantly affect cash flow performance.

Several other policy variables also had a significant influence on project performance outcomes. For example, increases in the quality goal on the Major Project and the magnitude of the new proposals capture rate worsens schedule performance. Increases in the negotiated overhead rate worsens DOD cost and total cost

performance. Increases in the contractor's share of cost overruns and increases in the contractor's fee are both shown to improve cost control performance. Finally, increasing the overhead rate improves, as expected, cumulative cash flow performance.

3.3 Analysis of Endogenous Performance Variables

The objective of this section is to discuss in more detail the results of the sensitivity analysis with respect to various endogenous performance variable. The focus is on the sensitivity of the various performance indices to policy instruments. In addition, emphasis was given to long-run effects (i.e., overall and/or later periods of the simulation as opposed to immediate short-term effects) due to the desire to minimize initial condition effects.

3.3.1 Schedule Performance

High target costs and low weights assigned to overall past performance and to proposal quality were shown to improve schedule performance. Similarly, higher minimum levels of acceptable quality performance on the Major Project worsen overall schedule performance in years 2-5 but the effect is reduced in the later years of the simulation. This is expected because the Major Project was usually completed by the third or fourth years of the simulation. Higher negotiated overhead rates were shown to be associated with improved performance; in this case the effect becomes more pronounced in the later years after expiration of the

Major Project. This is consistent with our intuition that higher overhead rates, ceteris paribus, increases internal capacity and subsequent project performance indices.

3.3.2 Cost Control Performance

As discussed in the previous section, a larger and higher quality workforce can be expected to reduce cost overruns. This is confirmed in all three periods under analysis. Similarly, higher target costs, ceteris paribus result in smaller cost overruns. Finally, the long-run (years 4-5) effect of the sharing proportion on cost control should be mentioned. Increasing the sharing proportion results in improved cost control--but not until the late periods of the simulation when the Major Project is completed. This results from not specifying intermediate cost and performance milestones for the major project.

3.3.3 Quality of Performance

The prominent determinants of performance are the proposition of the initial workforce considered high quality and the relationship of target costs to estimated costs. As expected, increasing the quality of the workforce allows the Project Manager to improve project performance quality.

Increases in target costs are shown to influence performance quality: the higher the target costs, ceteris paribus, the higher the resultant quality. In

the later periods, higher maximum backlog goals are associated with lower quality. An explanation for this latter influence is that a Project Manager concerned with maintaining backlog and securing new projects (i.e., growth) is likely to utilize high quality personnel on indirect (proposal writing) activities rather than direct.

3.3.4 DOD Cost Efficiency

The regression results suggest that the costs per SQMM are strongly influenced by the negotiated overhead rate. Higher overhead rates are consistently associated with higher costs. In addition, the higher the weight assigned to past performance quality in the capture rate calculation the lower are costs in the long-run.

3.3.5 Social Cost Efficiency

The sensitivity analysis corresponding to total social costs per SQMM (i.e., the amount billed to the DOD as well as the cost overruns, if any, absorbed by the contractor) indicated that the overhead rate plays a strong role in determining total costs per SQMM. However, social cost efficiency is influenced by initial policy instruments including the weight assigned to overall (average and variance of quality) past performance, the range of ceiling over target costs, and to a lesser extent, the contractor's share of cost overruns. An interesting result is that, all else equal, higher

ceiling costs and sharing proportions, improve social efficiency.

3.3.6 Project Manager Considerations

The operational concerns of the Project Manager: the average size of the workforce, level of backlog and quality of personnel were shown to be associated with the capture rate on new proposals and are generally significant predictors of Project Manager performance concerns as to the target cost relative to estimated costs.

The positive influence of the new proposals capture rate on the average size of the workforce was expected because a higher capture rate, all else equal, will result in more projects being awarded and a greater opportunity for the Project Manager to expand the size of the staff. Likewise, increasing the range of ceiling over target costs was expected to provide inducements for expansion of staff.

A somewhat puzzling result at first glance is the significant short-run effect of high Major Project quality standards on labor force size. A possible explanation is that higher quality standards will often result in a temporary period of operational problems when the Major Project is being completed -- i.e., schedule delays and cost overruns due to additional work being required and backlog concerns as high quality personnel are transferred from proposal writing

activities. In order to compensate for the attrition of high quality workers that is likely to occur as a result of these problems, the Project Manager will quickly expand the workforce when the Major Project is brought under control. The net result is a larger, but lower quality labor force.

As discussed above higher capture rate values result in increases in the size of the labor force. Due to the relative scarcity of high quality personnel, however, this expansion causes a lower average quality workforce. This, as before, is due to the temporary operational problems incurred in meeting standards and the resultant attempts of the Project Manager to compensate for labor force attrition and to maintain capacity by hiring readily available low quality personnel.

3.3.7 Corporate Considerations

Cumulative cash flow were shown to be significantly affected by several initial conditions including backlog goals and the size of the labor force. Large values for total labor and higher backlog goals are associated with improved (higher) values of cash flow. Higher capture rates for new proposals have the expected positive effect on cash flow as do higher overhead rates, target costs and smaller (but larger numbers of) contract awards. The proxy for contractor profitability, net contract awards. The proxy for contractor profitability, net cash flow as a percent of billings, was

generally insensitive to variations in the independent variables under analysis.

3.4 Conclusion

The sensitivity analysis phase of the research has provided additional insights as to the basic properties of DPM behavior. Rather than constraining the investigation of DPM performance determinants to several (pre-specified) combinations of policy instrument settings (scenarios), the multiple regression experiment allows for the simultaneous evaluation of many independent variables over wide ranges of possible values. A valuable side-effect of this approach is that the DPM is implicitly subjected to an array of consistency and plausibility checks which are necessary and vital components of the validation process.

Due to the aggregate nature of regression results, complex behavioral relationships endogenous to the DPM are often difficult to diagnose. This, of course, reflects to a certain degree on the nature of the economic system being analyzed and should not be considered a serious deficiency. In any case, attempts have been made throughout Technical Reports 1 and 2 to provide explanations of interactions when deemed necessary. Taken in combination the scenario analyses and the sensitivity analyses provided a reliable means to evaluate the internal logic and behavior of the DPM simulation.

SECTION 4: EXTERNAL VALIDATION INTERVIEWS*

4.1 Overview

This section describes the results of the external validation effort.

The approach taken was to conduct interviews with senior DOD personnel who have or had command responsibility for major systems development projects and with senior line managers at contractor organizations.

At the DOD level interviews were completed with General Bob Mathis (ret), Rear Admiral Wayne Meyer, General Alton Slay (ret) and Admiral Bud C. P. Ekes (ret) presently Vice President Boeing Aerospace Company. Contractor personnel with whom interviews were completed include Mr. Robert B. Norris, Manager Operational Planning Military Engine Division, Aircraft Engine Group, General Electric Company, Mr. J. R. Utterstrom, Vice President and General Manager, Air Launched Cruise Missile Program, Boeing Aerospace Company and Dr. Sidney W. Hess, Vice President and General Manager, Aerospace Division, ICI Americas, Inc.

* This section is adapted from Technical Report #3.

The interviews followed a semi structured open ended format. Each interviewee received an explanation of the purpose of the interview and was also informed of the reference person who recommended that he be contacted. The explanation of purpose described in general terms the nature of the research effort to date, the purpose of external validation and concluded with an expression of hope that the interviewee would consent to a free form discussion and sharing of his experience with the principal investigator. In all cases the individuals contacted agreed to be interviewed. However, because of scheduling conflicts and personal reasons interviews were only completed with individuals named above. The interviews are being characterized as semi structured and open ended because for each group of interviewees they covered a specific set of subjects. The order of the issues discussed varied across interviews, because the open ended format led to the exploration of additional topics which were of interest to the interviewee or to the principal investigator. The interviews with Mr. Norris, Mr. Utterstrom and Dr. Hess were held in person. The interviews with General Mathis, Rear Admiral Meyer, Admiral Ekes and General Slay were conducted by telephone. The interviews ranged from one to two hours and in a number of instances involved follow up telephone calls. Because several of the individuals requested that findings should not be directly attributed to them the summary of the interviews which follows does not explicitly identify any individual. It should be noted that

the interview with Admiral Ekes (ret) explored the issues at both stages of his career (i.e., project manager Harpoon Missile, Chief CNM and more recently as V.P. Boeing Aerospace Company).

4.2 Summary of Interviews with Senior DOD Personnel

The purpose of the interviews with the senior DOD project commanders was to explore with them their thoughts and experiences with contractor motivation, monitoring project performance, means of exerting pressure on contractors, importance of past performance on award decision, incentive contracts and share ratios, role of IR&D, government weapons procurement policies, and perceptions of contractor internal organization and management style.

In general, all interviewees felt that program failures to meet technical specifications, delivery schedules and/or costs were rare occurrences and in the most spectacular cases were not entirely the fault of the contractor. Problems on system development projects were attributed to several causes - failures of contractor management, political factors (e.g., congressional appropriation process), project not of high priority to DOD, insufficient latitude in modifying project specifications, DOD project monitoring failed to pick up problems at early stages of project, contractor did not have appropriate technical capabilities, adversarial relations between the prime and the sub contractor, and/or frequent DOD redirection of project.

As to the aspect of monitoring the progress of projects, the interviewees agreed that cost, schedule and technical performance were the primary factors which needed to be tracked in detail. However, two interviewees considered technical performance to be the primary criteria and one considered cost performance to be the most important criteria to be monitored.

Of particular interest were the interviewees descriptions of actions to be taken when problems are identified. There seems to be total agreement that in the first instant problems are to be resolved at the level of the project managers (DOD and contractor). It also became clear that the likelihood of local resolution of problems was a function of early identification and of the project manager discretion to adjust schedules, budgets and technical specifications.

When it becomes evident that problems are not being corrected the respondents agreed that the pressure level had to be escalated up the hierarchy. Each related specific examples from their experiences when problems had to be brought to the attention of higher level management. In addition to formal communication (through letters and meetings) Two respondents felt that on occasion, salvaging a project requires changes in the contractor management of the project. Such changes, they felt, can only come about through intervention with top management. The interviewees cited the withholding of progress payments and the withdrawal of the award fee (which the contractor earns up front) as

very effective means for getting top management attention. Examples cited included symbolic withholding of small amounts (e.g., \$100,000) to a very significant withholding of \$40,000,000 in a major case. They also stated that withholding of progress payments tend to be more effective in aerospace related programs and less effective in shipbuilding. It should be noted that the interviewees opinion that contractors are extremely sensitive to their cash flow and the withholding of progress payments are at variance with the views of DOD project managers interviewed in Phase 1 (Contract #F33615-79-C-5151) described in Technical Report #3, pp. 1-4. This may be accounted for by the higher ranks of the interviewees or because of their direct experience with the withholding of progress payments.

The interviewees disagreed on how to structure the contractual relationship. Two respondents felt strongly that it is more effective to accomplish systems development projects on a cost plus fee basis and that it is an impossibility to write "perfect" contracts with "perfect" specifications. In the words of one interviewee, "complex undertakings must have a lot of elastic". Whereas, the above sentiment was also voiced by the other interviewees they felt, to varying degrees, that firm fixed price contracts or incentive contracts with punitive share ratios are effective and can be written.

It was clear that the respondents voiced basic disagreements regarding the use of different contractual

relationships. One respondent argued that competitively awarded fixed price contracts lead to contractor ripoffs of the DOD (in terms of technical quality and ease of service and maintenance) which inevitably lead to higher life cycle costs. Another respondent felt that firm fixed price contracts "incentivize" the contractor on project costs and therefore it should not come as a surprise that the contractor compromises the technical requirements of the project. This same respondent preferred a cost plus award fee type contract, with the award fee tailored to the achievement of technical and cost milestones.

As to incentive type contracts the interviewees were in complete agreement that unless the share line is punitive (40-60%) and unless ceiling costs are within 25% of target costs such contracts will motivate contractors to exceed target costs and tend to subsidize the size of engineering staffs.

The interviewees were in general agreement as to the role of IR&D funds in furthering technological innovation. One respondent described IR&D funds as "high leverage dollars to fuel applications research". Another made a causal connection between IR&D funds and the flow of new ideas from contractor laboratories to the DOD. And another felt that U. S. technological superiority in weapon systems could be traced to the tradition of IR&D funds and the competition which it fostered between vendors for new ideas and for the application of technology.

The interviewees also provided many miscellaneous comments and opinions. One interviewee made a distinction between shipbuilding projects which are built one at a time (i.e., custom products) and aerospace projects which are built in series. He felt that cost overruns and failure to achieve technical specifications are more likely in shipbuilding programs because of great sensitivity to engineering change orders. In aerospace projects the learning curve invariably should lead to the achievement of increasingly higher technical specifications and better costs.

Another respondent noted that in aerospace projects the contractor is responsible for all phases of the project from design to production. Whereas shipbuilders are primarily constructors, building to specifications prepared by naval architects which implement designs originated by the Navy. As a result, shipbuilders are less involved in a project. Success or failure does not reflect on their professional capabilities in design, technological innovation of weapon systems or their application.

The interviewees were all of the opinion that contractor past performance should be factored into the award decision of a new contract. They stated that past performance had been considered on projects they were involved with. However, they also felt that the source selection panel "has to be subjective" in its consideration of past performance and that the source selection is influenced by past association with contractors. One respondent noted that the services have,

over the years, developed close working relationships with certain contractors which leads to "rationalizing past performance" and "favoring" of incumbent contractors when new awards are made.

On balance the interviews with senior DOD project managers closely reflect the interviews conducted with DOD project managers in Phase 1 which were summarized in Technical Report #3. The more senior officers, interviewed as part of the external validation effort, were more explicit about the effectiveness of withholding progress payments as a means to getting corporate attention when serious problems remain uncorrected. The senior officers were much more explicit in their views that defense contractors are organized to manage their cash flow. Similarly the senior officers supported earlier statements about the role of IR&D funds.

It was of interest to note that the senior officers were in disagreement regarding structuring of the contractual relationship. The DPM results for example suggested the use of cost plus fee type contracts for research and development type contracts up to a point where reliable estimates can be made of the technological gap which remains to be overcome. At that point switching to firm fixed price incentive contracts was the preferred alternative. This concept was supported by two respondents.

The DPM results also indicated that for incentive type contracts to have an impact on contractor management of projects, the share ratios must be more punitive. Three of

the senior officers explicitly supported the idea of share ratios in the 40-60% range. One respondent also felt that "ceiling" cost should not exceed 125% of "target" cost.

The interviews also highlighted apparent differences between aerospace projects and shipbuilding projects and by indirection a distinction between research and development and production projects. The structure of the DPM best fits aerospace system development projects. Indeed it was not designed to simulate either "one at a time" projects such as shipbuilding nor series production programs such as missiles or fighter planes. In addition the DPM does not attempt to simulate project success or failure which are attributed to the internal operating style, organization design and management quality of contractor organizations. Neither does the DPM make distinctions between prime and sub contractors.

4.3 Summary of Interviews with Contractor General Managers

The interviews with contractor senior managers followed the same pattern and had the same basic purpose as those with senior DOD personnel.

With the exception of one interviewee, it was clear that cash flow is an important financial measure which division managers* track by project. In addition, these managers were also tracking new contracts (backlog), indirect costs, management ratios, and capital investment projects (including IR&D projects).

* Project Manager in the DPM

One manager was quite explicit in noting that the division was not practicing shifts in personnel from direct to indirect categories and vice versa as a means to managing cash flow. The clear implication was that the division was targeted in the corporate strategic plan for investment and therefore cash flow or division profits in the short run were immaterial. It was implied that if the division had been designated a mature business, corporate management in all probability, would have been concerned with cash flow and bottom line contribution.

All the managers indicated a preference for contracting development projects on a cost plus fee basis. One manager thought it reasonable to contract early phases of development on a cost plus fee basis and on a fixed price incentive basis for the concluding phases. One manager was not willing to discuss alternative incentive contracts involving greater sharing of cost overruns as a function of various sharing proportions and target and ceiling costs. The other three managers, in general, agreed that low cost sharing formulas (in the 10-20% range) did not create incentives to minimize costs and more likely subsidized excessive staffs and other costs (e.g., data processing). Two managers noted that high sharing proportions and/or low ceilings relative to target costs would lead to more realistic bidding and therefore to lower cost overruns. One manager thought that most cost overruns occur as a result of deliberate low bidding and/or because of the inducements built into the incentive contract

parameters (low sharing ratios and high ceilings relative to target).

As to relations with DOD project managers the general sentiment was that it was best to resolve problems at the project level. Two managers felt that whether a problem got resolved or became a major issue was a function of the latitude built into the contract specifications. One manager gave the example of test firings where the contract was behind on the number of test firings. However, the DOD project manager, accepted the project because all the test firings which were made (75% of total required) exceeded performance specifications.

Another manager cited an example of a missile engine project which was one year behind schedule. Yet because of an ability to adjust costs and schedules the project was not considered to be in "default".

The managers considered IR&D funds as a strategic pool of resources with a direct impact for experimenting with new ideas, proposing new or follow-on projects or for bidding on new projects. One manager characterized IR&D projects as the key to his firm maintaining technological superiority. Another described in detail the corporate process of committing research and development funds and the importance attached to the decision allocating corporate funds to augment IR&D funds.

The managers were explicit as to the transferability of military research and development to commercial use.

Specific examples were given in terms of jet engine development, transport aircraft and explosives technology. One manager felt that the transfer of commercial technology to aerospace military related applications was immaterial.

The managers did express dissatisfaction with DOD unwillingness to create appropriate risk/reward situations especially when companies put up their own risk capital for plants and equipment. Another manager made a comparison to electric utilities who, he believed, were guaranteed by public utility commissions higher rates of profitability under less risk than what the DOD allows its contractors under conditions of greater risk.

One manager also felt that contractors were at a disadvantage when bidding on a project where a "special relationship" does not already exist between the military service and the company. He expressed the view that as long as special relationships dominate, "past performance" will not become a significant factor in the award decision. It was also clear that the "feast or famine" approach to procurement of defense systems and the "politics of defense" were viewed as major factors adding to the perceived risk of being in the military systems research and development business (these sentiments of course predate the present climate for defense business).

The interviewees were also asked to comment on the issue of competition for scarce technical talent. One manager noted that in a climate of contraction top talent had been let go and that many more left voluntarily. Another manager

noted that his company was always searching for highly trained and experienced technical personnel and that turnover and growth stimulated competition for talent. However, he noted that in his company hiring "into overhead" required his authorization.

4.4 Summary and Other Feedback

During the three years of this research project the investigators have had occasion to present various aspects of the research at national meetings of TIMS/ORSA, two Winter Simulation conferences, an AFBRMC Workshop on Contractor Motivation, and to the DOD Comptroller, Dr. Jack Borsting and members of his staff. In addition, the principal investigator and Major Robert F. Golden (AFBRMC/RDCB) on July 6, 1981 briefed General Joseph H. Connolly (HQUSAF/RDC) at the Pentagon on the research and its potential for evaluating alternative procurement policies.

The value of presentations at professional meetings is in the informal give and take and the focus on potential applications, limitations of the model, suggestions for further research and comparisons to prior research. The interest of Dr. Borsting and his staff and General Connolly seemed to center on the potential application of the DPM in policy making involving system development and acquisition.

Of special interest, to them, were the findings that suggest the need for structuring incentive contracts embodying significant cost overrun sharing proportions (40% - 70%) combined with relatively low ceilings (110% - 125% of target

costs). These findings are consistent with the validation interviews. After the fact it seemed intuitively reasonable to link cost overruns to the structure of cost incentive contracts which in reality place a low economic penalty on underestimating total costs and/or which provide the incentives to build technical capabilities at a significant subsidy.

Similarly the findings which support a stable moderately increasing weapons development and acquisition program in contrast to an uncertain and fluctuating demand by DOD also seemed to be intuitively appealing. Thus a certain credibility can be attributed to the overall model and to its potential use in assisting policy makers. However, the DPM model as presently structured is more appropriate for system development projects such as new missiles, new jet engines, new radar and new fighter planes, than for "one at a time" projects such as shipbuilding or series production. This is because the structure of the model includes specific sub models for proposing and securing new R&D business and spinoff projects. The DPM model does not include a manufacturing assembly sub model.

Researchers and other scholars have noted that the DPM needs to be further validated. While the overall approach to the design of the DPM seems supportable, questions have been raised as to the validity of certain behavioral attributes which have been incorporated into the model and the absence of others (e.g., adaptive learning by key decision makers).

On balance, however, the model and its findings appear reasonable and lends further support to a behavioral alternative of the traditional economic theory of the firm.

Any external validation of the type attempted in this case has certain limitations. The managers being interviewed represent a convenience sample. It is also difficult to arrange meetings with the appropriate policy makers. In addition, there is always a certain reluctance on the part of managers to discuss certain issues. Similarly they are motivated to describe their firm or their project management philosophy or practices in favorable terms. Nevertheless, many of the comments are clearly supportive of basic features incorporated in the DPM. Most notably the sensitivity to pressures (from DOD project managers or corporate management), importance of withholding progress payments, backlog and spinoff projects, competition for scarce technical personnel and the influence of traditional incentive contract on cost efficiency. The interviews also confirmed that incentive contracts embodying high cost overrun sharing proportions with low ceilings relative to target costs would lead to more realistic bidding and therefore to fewer cost overruns. However, it is not clear from the interviews whether such contracts would result in overall higher cost efficiencies and therefore lower total costs. The interviews also supported the preference (and effectiveness) of cost plus fee development contracts.

The corporate interviewees and one senior DOD officer clearly felt that fluctuations in DOD demand is a major cause for poor project performance, underestimation of costs by bidders and overselling of achievable technical specifications. The results of the DPM simulation clearly lend support for a stable moderately increasing acquisition program as a means to achieving improved project performance, reduce contractor concern with survival and increase cost efficiencies.

The interviews yielded conflicting information on the issue of management concern with cash flow. Maximizing cash flow is an important behavioral characteristic of the DPM. There was an evident reluctance to discuss internal practices, yet the strong impression was created by the respondents that cash flow considerations were important. If additional validation efforts are to be undertaken it should be feasible to design a survey questionnaire aimed at a larger sample of contractor and DOD managers. Such a survey would draw on the insights gained from the interviews and should also probe the various policy implications derived from exercising the DPM.

SECTION 5: CONCLUSION

The major practical use of building a DPM type simulation is its ultimate application in answering "what if" type policy questions involving the design parameters of the contractual relationship between the DOD and defense contractors. For example, the simulation results indicated that increasing the contractor's fee improves cost control performance. This idea has recently been implemented by the Navy with measurable success. Another example involves the weight given to past performance in awarding new contracts. The DPM simulation results suggest that the higher the weight (including those assigned to the quality of the proposal) the better is cost control performance and social efficiency. Factoring past performance into the contract award decision was supported by senior DOD officers. The practical implications involve the feasibility of factoring past performance measures into a DOD contracting environment where often it is difficult to maintain a second source and where such evaluation is considered to be extremely subjective.

The research effort, in our view, clearly demonstrates the value of such a simulation model for analyzing alternative acquisition policies (e.g., the importance of maintaining stable demand, weighting past performance, etc.) and the design of contract incentives (size of fee, schedule of progress payments, target and ceiling costs and sharing proportions). In particular it could augment traditional analytical and intuitive approaches to these issues. Its

routine use in this mode, by the Air Force, will depend on implementing its use within the relevant command responsible for acquisition policies and the design of incentive contracts.

A simulation model of this type has other uses. Of particular interest should be its potential use in the training or education of policy makers and or DOD project managers. In business education similar simulation models have been designed as management games. Such games, which can be extremely complex, are used as laboratories for training students to apply analytical tools and integrate functional areas knowledge (marketing, production, accounting, financial planning, etc.) within a competitive decision making environment. The DPM simulation has the potential to be integrated into an "Acquisition Game" and/or a "Project Management Game" for project managers. It could also be used in the education of policy makers (e.g., Congressmen, senior staffs) when they need to develop insights into DOD acquisition policies. The current state of the DPM simulation cannot be immediately used in acquisition training. However, it should be at the core of an acquisition game which could be designed.

In summary, the total research effort has produced a simulation model involving the DOD and the contractor organization at the corporate and project management levels. The simulation has been shown to be internally robust and to satisfy certain face validity criteria. In particular its

potential application to acquisition related policy making has been demonstrated. It is in the area of contributing to policy making and project management training where future developments need to be directed.

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